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CALCULATED EFFECTS OF FULL-SPAN SLOTTED AND FOWLER FLAPS ON LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS FOR A TYPICAL FIGHTER-TYPE AIRPLANE WITH VARIOUS TAIL MODIFICATIONS

By R. Fabian Goranson

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE [redacted] REPORT

CALCULATED EFFECTS OF FULL-SPAN SLOTTED AND FOWLER FLAPS ON LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS FOR A TYPICAL FIGHTER-TYPE AIRPLANE WITH VARIOUS TAIL MODIFICATIONS

By R. Fabian Goranson

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SUMMARY

An analytical study has been made of the influence of full-span slotted and Fowler flaps on the requirements for horizontal tail surfaces. The individual and combined effect of changes in tail area and aspect ratio have been considered.

Elevator deflection required to land at three-point attitude, elevator deflection required to stall the airplane at altitude, and permissible center-of-gravity range have been calculated for a fighter-type airplane and the results are presented in tabular form.

The results show that a moderate increase in tail volume will satisfy the demands of flaps (such as the slotted type) which give moderate lift and pitching-moment increments, but when a large permissible center-of-gravity range is desired with these flaps or if flaps which give large lift and pitching-moment increments (such as the Fowler flap) are used, the provision of an adjustable stabilizer is mandatory if abnormally large tail surfaces are to be avoided.

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, an analytical study has been made of the influence of full-span flaps on the requirements for horizontal tail surfaces. The basic dimensions of a typical fighter-type airplane were used as a basis for calculating the effects of variations in tail length, tail area, and tail aspect ratio on the longitudinal characteristics obtained with full-span slotted and Fowler flaps.

METHOD OF CALCULATION

The calculations are based on the method outlined in reference 1. It was possible, when reference 2 became available, to extend the method of reference 1 to the calculation of elevator deflections required for landing.

The dimensions of the airplane on which the calculations are based are listed in table I. Also listed are the dimensions of the tail modifications investigated with the various flap arrangements.

The characteristics of the flaps were taken from references 3 and 4 for a 0.25-chord slotted flap and a 0.25-chord Fowler flap, respectively. The maximum deflection of both flaps was assumed to be 40°.

The angle of incidence of the stabilizer was assumed to be 0° except in the case of the unmodified airplane with the flaps retracted, where the original setting of $1\frac{1}{2}$° was used. Changes in tail length were obtained by changing the distance from the quarter-chord point of the wing root, rather than from the center of gravity, in order to fix the reference point.

DEFINITION OF SYMBOLS

$d\delta_e/d\alpha$ rate of change of elevator angle with angle of attack

x distance from root quarter-chord point to elevator hinge line, measured parallel to thrust line

S_t total horizontal-tail area

A_t aspect ratio of tail

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b_t tail span

δ_e elevator angle, positive when trailing edge is below neutral position

$\delta_{e_{stall}}$ elevator angle required to stall the airplane at altitude

$\delta_{e_{land}}$ elevator angle required to land at three-point attitude

i_t angle of incidence of stabilizer relative to thrust line, positive when leading edge is higher than trailing edge

$C_{L_{stall}}$ maximum wing lift coefficient at which tail stalling occurs

c_s root wing chord

RESULTS AND DISCUSSION

The results of the calculations are listed in table II. The data for each configuration are divided into four vertical groupings as follows:

1. Line drawing of airplane together with basic dimensions

2. Stability and control characteristics with flaps retracted

3. Stability and control characteristics with slotted flap

4. Stability and control characteristics with Fowler flap

The stability and control characteristics are presented for the limiting center-of-gravity positions as determined by the values of these characteristics necessary for acceptable flying qualities. The horizontal rows of the table present data for the following center-of-gravity positions:

1. Most rearward center-of-gravity position allowable to maintain passable longitudinal stability with flaps up (A value of $d\delta_e/d\alpha$ of 0.18 was taken as a minimum limit.)

2. An arbitrarily fixed center of gravity at 28.5 percent mean aerodynamic chord to provide a ready comparison of the effectiveness of the various changes,

3. The most forward center of gravity as limited by the power of a 30° elevator deflection to maintain three-point attitude during landing with the stabilizer fixed at zero incidence.

4. The most forward center of gravity as limited by item 3 if the stabilizer were adjustable to a -5° incidence for landing

The elevator angles listed in table II for the landing condition frequently exceed -30°. These angles were computed on the assumption that the elevator effectiveness was constant over an unlimited range of deflection. Although this assumption is obviously incorrect for large deflections, the angles shown indicate where and by how much the elevator requirement is exceeded.

The tabulated data may be summarized as follows:

1. The critical elevator requirement in every case is the deflection necessary to maintain three-point attitude in landing.

2. The principal effect of increased effective tail volume is to permit a more rearward position of the center of gravity (without instability when flaps are retracted), thus decreasing the elevator deflection required for three-point landing.

3. Satisfactory characteristics with the full-span slotted flap would exist within the following limits of center-of-gravity positions:

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[The tail-volume ratio is the ratio of the tail volume to that of the original airplane]

Configuration (See table II.)			Center-of-gravity range for satisfactory stability and control, percent M.A.C.	
	Tail-volume ratio	Tail aspect ratio	Fixed stabilizer	-5° adjustable stabilizer
A	1.0	3.81	None	25.7 - 28.5
B	1.0	5.0	30.1 - 30.1	24.0 - 30.1
C	1.25	3.81	29.1 - 31.0	23.2 - 31.0
D	1.19	5.0	28.5 - 32.5	22.9 - 32.5
E	1.25	3.81	30.3 - 31.3	24.1 - 31.3
F	1.25	5.0	29.4 - 33.5	22.2 - 33.5
G	1.56	3.81	28.5 - 35.0	21.1 - 35.0
H	1.49	5.0	28.5 - 36.5	19.4 - 36.5

4. Satisfactory characteristics with the full-span Fowler flap would exist within the following center-of-gravity limits:

Configuration (See table II.)			Center-of-gravity range for satisfactory stability and control, percent M.A.C.	
	Tail-volume ratio	Tail aspect ratio	Fixed stabilizer	-5° adjustable stabilizer
A	1.0	3.81	None	None
B	1.0	5.0	- do -	30.1 - 30.1
C	1.25	3.81	- do -	29.2 - 31.0
D	1.19	5.0	- do -	27.5 - 32.5
E	1.25	3.81	- do -	29.8 - 31.3
F	1.25	5.0	- do -	27.5 - 33.5
G	1.56	3.81	32.9 - 35.0	26.6 - 35.0
H	1.49	5.0	32.2 - 36.5	24.7 - 36.5

5. Tail stalling will occur at fairly low speeds when flaps are fully deflected with the stabilizer adjusted to maximum negative incidence. The adjustable stabilizer, however, is necessary only to permit the three-point attitude during landing; the airplane can be stalled at altitude, flaps extended, with reasonable elevator deflection, and without tail stalling with the stabilizer neutral.

The present study was chiefly concerned with the requirements of horizontal-tail size and tail length for providing sufficient control power and stability. The aerodynamic balance required of the control surfaces for satisfactory control forces is obviously increased over that required of the unmodified airplane, particularly for the maneuvering condition of flight with the large tail areas shown.

As a matter of interest, the maximum lift coefficients obtainable with the various tail configurations were calculated by the method of reference 5 and corrected for the tail load required at the most forward allowable center-of-gravity positions. The ground effect, which unpublished data indicate may cause a reduction in maximum lift coefficient, has been neglected in these calculations. The results are presented in the following table:

Configuration (See table II.)			Maximum lift coefficient			
			Fixed stabilizer		Adjustable stabilizer	
Airplane	Tail-volume ratio	Tail aspect ratio	Slotted flap	Fowler flap	Slotted flap	Fowler flap
A	1.0	3.81	----	----	2.52	----
B	1.0	5.0	2.55	----	2.48	2.83
C	1.25	3.81	2.54	----	2.48	2.82
D	1.19	5.0	2.53	----	2.47	2.80
E	1.25	3.81	2.56	----	2.50	2.86
F	1.25	5.0	2.56	----	2.49	2.86
G	1.56	3.81	2.55	2.90	2.48	2.83
H	1.49	5.0	2.55	2.89	2.47	2.81

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CONCLUSIONS

On the basis of this study it may be concluded that the use of full-span flaps greatly increases the demands made on the horizontal tail. With flap types giving moderate lift and pitching-moment increments (such as the slotted flap) it appears practicable to take care of the increased tail requirements simply by an increase in tail volume over that conventionally used. With full-span flaps giving large lift and pitching-moment increments (such as Fowler flaps) or with flap types giving moderate lift and pitching-moment increments when large permissible center-of-gravity variations are desired, the provisions of an adjustable stabilizer appears mandatory unless tail volumes far greater than those normally required are used.

REFERENCES

1. Gilruth, R. R., and White, M. D.: Analysis and Prediction of Longitudinal Stability of Airplanes. Rep. No. 711, NACA, 1941.

2. Katzoff, S., and Sweberg, Harold H.: Ground Effect on Downwash Angles and Wake Location. T.N. No. 845, NACA, 1942.

3. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Various Arrangements of Slotted Flaps. Rep. No. 664, NACA, 1939.

4. Harris, Thomas A., and Purser, Paul E.: Wind-Tunnel Investigation of an NACA 23012 Airfoil with Two Sizes of Balanced Split Flap. NACA A.C.R., Nov. 1940.

5. Pearson, H. A.: Span Load Distribution for Tapered Wings with Partial-Span Flaps. Rep. No. 585, NACA, 1937.

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TABLE I

DIMENSIONS OF AIRPLANE USED IN CALCULATIONS

Configuration change	Original airplane	$1.25S_t$	1.25x	S_t original $A_t = 5.0$	$1.25b_t$ $A_t = 5.0$
Wing area, sq ft	260.0				
Wing span, ft	38.0				
Wing aspect ratio	5.56				
Wing taper ratio	1.67				
Wing incidence, deg	0				
Wing airfoil section	NACA 230 series				
Wing root chord, c_s, ft	8.57				
Wing M.A.C., ft	7.01				
Total horizontal-tail area, S_t, sq ft	49.05	61.3		49.05	58.5
Elevator area back of hinge line, sq ft	18.62	23.3		18.62	22.2
Elevator balance area, sq ft	4.96	6.2		4.96	5.92
Tail span, b_t, ft	13.67	15.28		15.65	17.1
Tail aspect ratio, A_t	3.81	3.81		5.0	5.0
Stabilizer incidence relative to thrust line, i_t, deg	1.5	0	0	0	0
Length of fuselage, ft	25.8		30.3		
Maximum fuselage width, ft	4.6		4.6		
$c_s/4$ to nose of fuselage, ft	6.2		6.2		
$c_s/4$ to elevator hinge line, x, ft	17.9		22.4		
$c_s/4$ to propeller plane, ft	7.0		7.0		
propeller diameter, ft	9.75				
Weight, full load fighter, lb	7063				

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TABLE II

CALCULATED LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS
WITH FULL-SPAN FLAPS AND VARIOUS TAIL MODIFICATIONS

[c.g. positions are given in percentage M.A.C.]

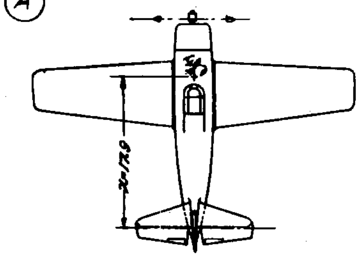
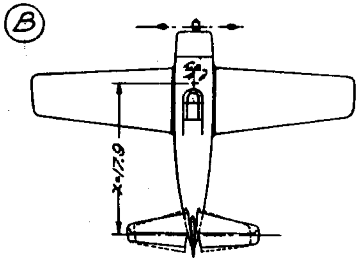
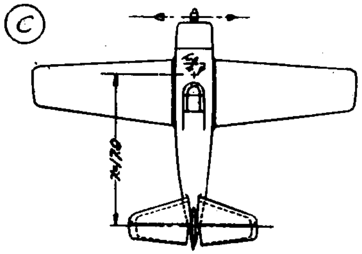
Configuration	Basic tail configuration changes				c.g. description and determinant	Flaps retracted				Slotted flaps						Fowler flaps					
	x (ft)	S_t (sq ft)	A_t (sq ft)	b_t (ft)		c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	To land at δ_e = -30°: i_t (deg)	To land at δ_e = -30°: $C_{L_{stall}}$	c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	To land at δ_e = -30°: i_t (deg)	To land at δ_e = -30°: $C_{L_{stall}}$
(A) 	Original = 17.9	Original = 49.05	Original = 3.81	Original = 13.67	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	28.5	0.18	-5.0	-18.0	28.5	0.47	-21.0	-36.8	-3.8	0.81	28.5	0.38	-34.0	-48.5	-10.4	1.92
					c.g. 28.5 for all configurations	28.5	.18	-5.0	-18.0	28.5	.47	-21.0	-36.8	-3.8	.81	28.5	.38	-34.0	-48.5	-10.4	1.62
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					c.g. back of maximum rearward position						c.g. back of maximum rearward position					
					Most forward c.g. to land, δ_e = -30°, i_t = -5°					25.7	.61	-14.2	-30.0	-5.0	.93	c.g. back of maximum rearward position					
(B) 	Original = 17.9	Original = 49.05	5.0	15.65 = 1.14 original	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	30.1	0.18	-2.2	-15.2	30.1	0.48	-13.7	-29.5	0	----	30.1	0.39	-24.1	-38.6	-4.8	1.30
					c.g. 28.5 for all configurations	28.5	.25	-3.5	-16.5	28.5	.56	-16.2	-32.0	-1.1	----	28.5	.47	-26.8	-41.3	-6.3	1.53
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					30.1	.48	-13.7	-29.5	0	----	c.g. back of maximum rearward position					
					Most forward c.g. to land, δ_e = -30°, i_t = -5°					24.0	.76	-14.0	-29.8	-5.0	0.93	30.1	.39	-24.1	-29.7	-5.0	1.30
(C) 	Original = 17.9	1.25 original = 61.3	Original = 3.81	15.3 = 1.12 original	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	31.0	0.18	-2.1	-15.1	31.0	0.47	-11.6	-27.4	0	----	31.0	0.38	-21.2	-35.7	-3.2	1.03
					c.g. 28.5 for all configurations	28.5	.31	-4.4	-17.4	28.5	.59	-15.5	-31.3	-0.7	0.61	28.5	.55	-25.5	-40.0	-5.6	1.37
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					29.1	.56	-14.4	-30.2	0	----	c.g. back of maximum rearward position					
					Most forward c.g. to land, δ_e = -30°, i_t = -5°					23.2	.81	-13.9	-29.7	-5.0	1.10	29.2	.49	-15.4	-29.9	-5.0	1.30

TABLE II - Continued
CALCULATED LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS WITH FULL-SPAN FLAPS AND VARIOUS TAIL MODIFICATIONS
[c.g. positions are given in percentage M.A.C.]

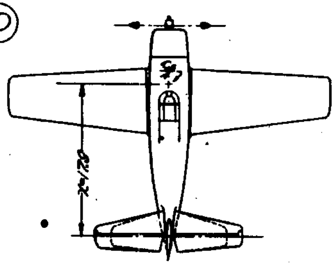
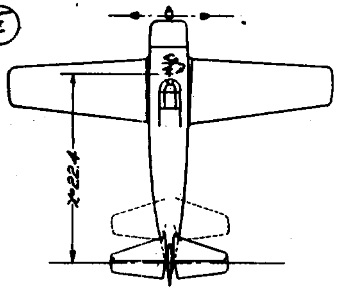
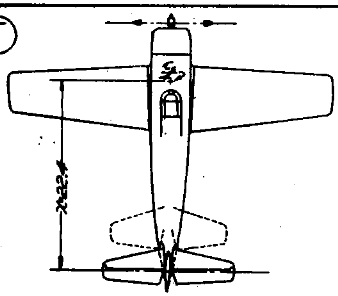
Configuration	Basic tail configuration changes: x (ft)	S_t (sq ft)	A_t (sq ft)	b_t (ft)	c.g. description and determinant	Flaps retracted: c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	Slotted flaps: c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	To land at δ_e = -30°: i_t (deg)	$C_{L_{stall}}$	Fowler flaps: c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	To land at δ_e = -30°: i_t (deg)	$C_{L_{stall}}$
D 	Original = 17.9	58.5 = 1.19 original	5.0	1.25 original = 17.1	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	32.5	0.18	-2.0	-15.0	32.5	0.49	-9.1	-24.9	0	----	32.5	0.38	-16.9	-31.4	-0.8	0.68
					c.g. 28.5 for all configurations	28.5	.34	-5.2	-18.2	28.5	.65	-14.3	-30.1	0	----	28.5	.57	-22.8	-37.3	-4.1	1.16
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					28.5	.65	-14.3	-30.1	0	----	c.g. back of maximum rearward position					
					Most forward c.g. to land, δ_e = -30°, i_t = -5°					22.9	.85	-12.2	-30.0	-5.0	----	27.5	.62	-15.3	-29.8	-5.0	1.27
E 	1.25 original = 22.4	Original = 49.06	Original = 3.81	Original = 13.67	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	31.3	0.18	-2.2	-15.2	31.3	0.56	-14.2	-28.5	0	----	31.3	0.46	-23.7	-36.7	-3.8	1.06
					c.g. 28.5 for all configurations	28.5	.32	-4.5	-17.5	28.5	.68	-18.3	-32.6	-1.5	0.77	28.5	.60	-28.0	-41.0	-6.2	1.37
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					30.3	.60	-15.8	-30.1	0	----	c.g. back of maximum rearward position					
					Most forward c.g. to land, δ_e = -30°, i_t = -5°					24.1	.86	-15.6	-29.9	-5.0	1.03	29.8	.53	-17.1	-30.1	-5.0	1.23
F 	1.25 original = 22.4	Original = 49.06	5.0	15.65 = 1.14 original	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	33.5	0.19	-2.2	-15.2	33.5	0.56	-10.5	-24.8	0	----	33.5	0.46	-17.7	-30.7	-0.4	0.65
					c.g. 28.5 for all configurations	28.5	.38	-5.8	-18.8	28.5	.75	-16.8	-31.1	-0.6	----	28.5	.67	-24.5	-37.5	-4.2	1.10
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					29.4	.72	-15.6	-29.9	0	----	c.g. back of maximum rearward position					
					Most forward c.g. to land, δ_e = -30°, i_t = -5°					22.2	.96	-15.7	-30.0	-5.0	1.02	27.5	.70	-16.9	-29.9	-5.0	1.17

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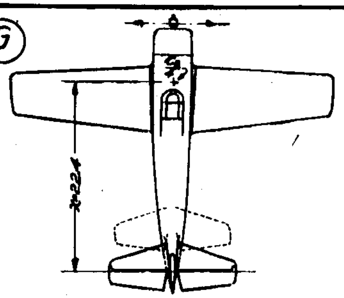
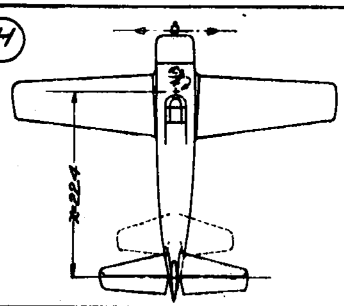
TABLE II - Concluded
CALCULATED LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS
WITH FULL-SPAN FLAPS AND VARIOUS TAIL MODIFICATIONS
[c.g. positions are given in percentage M.A.C.]

Configuration	Basic tail configuration changes				c.g. description and determinant	Flaps retracted				Slotted flaps						Fowler flaps					
	x (ft)	S_t (sq ft)	A_t (sq ft)	b_t (ft)		c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	To land at $\delta_e = -30^\circ$: i_t (deg)	To land at $\delta_e = -30^\circ$: $C_{L_{stall}}$	c.g.	$\frac{d\delta_e}{d\alpha}$	$\delta_{e_{stall}}$ (deg)	$\delta_{e_{land}}$ (deg)	To land at $\delta_e = -30^\circ$: i_t (deg)	To land at $\delta_e = -30^\circ$: $C_{L_{stall}}$
G 	1.25 original = 22.4	1.25 original = 61.3	Original = 3.81	15.3 = 1.12 original	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	35.0	0.18	-2.0	-15.0	35.0	0.56	-8.5	-22.8	0	----	35.0	0.45	-14.9	-27.9	0	----
					c.g. 28.5 for all configurations	28.5	.43	-6.3	-19.3	28.5	.78	-16.1	-30.4	-0.2	----	28.5	.71	-23.2	-36.2	-3.5	0.98
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					28.5	.78	-16.1	-30.4	0	----	32.9	.55	-17.5	-30.5	0	----
					Most forward c.g. to land, δ_e = -30° i_t = -5°					21.1	1.02	-15.5	-29.8	-5.0	1.01	26.6	.80	-16.9	-29.9	-5.0	1.20
H 	1.25 original = 22.4	58.5 = 1.19 original	5.0	1.25 original = 17.1	Most rearward c.g. $\frac{d\delta_e}{d\alpha}$ = 0.18, flaps retracted	36.5	0.18	-2.0	-15.0	36.5	0.57	-6.7	-21.0	0	----	36.5	0.46	-12.2	-25.2	0	----
					c.g. 28.5 for all configurations	28.5	.44	-7.0	-20.0	28.5	.82	-15.2	-29.5	0	----	28.5	.82	-21.4	-34.4	-2.5	0.91
					Most forward c.g. to land, δ_e = -30°, i_t = 0°					28.5	.82	-15.2	-29.5	0	----	32.2	.62	-17.1	-30.1	0	----
					Most forward c.g. to land, δ_e = -30°, i_t = -5°					19.4	1.06	-15.4	-29.7	-5.0	0.98	24.7	.89	-16.8	-29.8	-5.0	1.26